Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 121 (2015) 232 – 239
Procedia Engineering
www.elsevier.com/locate/procedia

9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE)

Simulation of Particles Diffusion Characteristics in the Ventilation Duct of the Air Conditioning System

Shanshan Wei[a], Yang Lu[b], Wentao Wu[a,b,*]

[a] *School of Civil Engineering, Dalian University of Technology, Dalian, China*

[b] *Johnson Controls Denmark, Denmark*

Abstract

PM2.5 and PM10 attach harmful substance easily and they pose a threat to health after being inhaled. Here deposits a large amount of PM2.5 and PM10 in the air conditioning system pipe surface, and they seriously affect the indoor air quality following by air into the room. This article analyzes the diffusion and propagation characteristics of PM2.5 and PM10 in the ventilation duct. The study focus on particles in the viscous sublayer and analyzes its movement. The study shows that the larger the wind speed, the faster particles reaching stable distribution; The velocity change of particles increases sharply, then decreases, remains stable finally; The final velocity (X direction) of particles of different size is same basically in the same duct with the same initial velocity(X direction); PM2.5 and PM10 are generally deposited on the bottom of the pipe within the range of the allowable wind velocity in the air conditioning system. Therefore, the paper concludes that in order to prevent the PM2.5 and PM10´s harm to the human, we should clean the ventilation duct regularly.

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015

Keywords: Ventilation duct; PM2.5; PM10; Diffusion characteristics

* Corresponding author. Tel.: 86-411-84707684-805; fax: 86-411-84706371.
E-mail address: lvyang@dlut.edu.cn

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015
doi:10.1016/j.proeng.2015.08.1062

1. Introduction

In recent years, a large number of cities appear continuous fog and haze, so the particle pollution attracts attention, especially the PM2.5 and PM10 have become the focus of attention in recent years. PM2.5 attaches harmful and toxic substances easily and there are the effects of causing mutation, cell transformation and inducing apoptosis. PM10 can accumulate in the respiratory system causing asthma and other diseases after being inhaled [1]. Due to the long-term improper operation and maintenance in air conditioning system, here deposits a large amount of PM2.5 and PM10 in ventilation duct surface. PM2.5 and PM10 follow air into the room seriously affecting indoor air quality and causing harm to people's health. So the study researching the movement of PM2.5 and PM10 in the ventilation duct is necessary.

In recent years, more and more researches focus on the movement and deposition characteristics of particles in ventilation duct. Zhao and Chen et al [2] analyzed deposition characteristics of particles in the ventilation duct numerically using a three-dimensional migration ventilation model ,and studied the deposition characteristics of particles with different size in the straight duct under two different average wind velocity. Ren Yi[3]simulated the laws of deposition of particles in the pipe elbows and tees using FLUNT software. LuZhen[4] simulated the suspension characteristics of particles in the duct using CFD. However, the research date about movement of PM2.5 and PM10 in different conditions is still lacking. This study simulates the movement of PM2.5 and PM10 in the straight pipe and bend and analyzes the law of motion using numerical simulation software named STREEM.

2. Research summary

2.1. Model summary

This study simulates in the straight pipe and bend. The straight pipe´s dimensions are L(x)×W(y) ×H(z)=10m ×4m×1m. The straight part of bend has the same size with the straight pipe, the bend radius is 2m. Inlet is located in the left of duct. Here sets a particle source (L(x)×W(y)=4m×1m) at the inlet of pipe, and there arranges 3000 particles uniform in the particle source. The pipe models are shown in figure 1 and figure 2.

Fig. 1. Straight pipe model

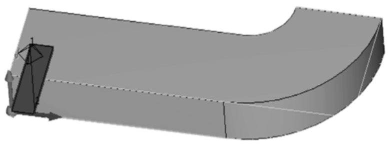

Fig. 2. Bend model

2.2. Working conditions summary

The wind velocity is in the range of 2.5-8m/s in the ventilation duct placed in the public buildings according to the 《HVAC System Design Manual 》. The article simulates the movement of PM2.5 and PM10 at 2.5m/s and 8m/s velocity. In this study, viscous sublayer is the key area of analyzing particles motion, so the first and second grids in the Z direction are divided at a ratio of 1.2, the other grids in the Z direction and X、Y direction are divided evenly. The number of grids of straight pipe and bend are shown in Table 1. Meshing detail in Figure 3 and 4.

Table 1. The number of grids

Pipe case	The number of grids（X×Y×Z）
Straight pipe	286×40×75=858000
Bend	457×60×69=1891980

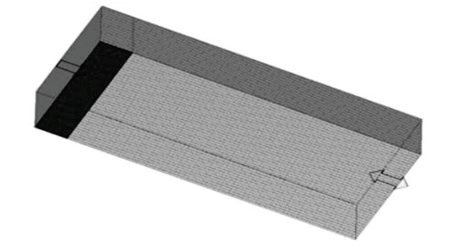

Fig. 3. Straight pipe meshing detail

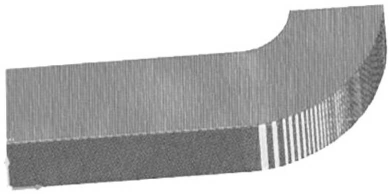

Fig. 4. Bend meshing detail

2.3. Numerical method

In the study, the flowing of air in duct is seen as an incompressible fluid turbulence. Turbulence model select the k- ε model. The simulation uses the equation as shown formula (1). The following assumptions is given in this simulation: the density of PM2.5 and PM10 is 1000 kg/m^3 [5]; particles will not be suspended after they fall in the bottom of pipe.

$$\frac{du_p}{dt} = F_D + \frac{g(\rho_p - \rho)}{\rho_p} + F_L \tag{1}$$

Where FD is the airflow force imposed on per unit mass of fluid；u is the airflow velocity；up is particles velocity； the second item in the right equation means gravity minus buoyancy imposed on per unit mass of fluid；FL is the Safuman force imposed on per unit mass of fluid.

2.4. Motion simulation

In the study, five conditions are simulated. It sets the initial velocity in X direction only, the initial velocity in Y、Z direction is assumed to be 0. Single cycle time is set to 0.02s in the STREEM. Five kinds of working conditions detailed in Table 2.

Table 2. Working conditions detailed

Case	Pipe	Particle size(μm)	Wind velocity(m/s)
①	Straight pipe	2.5	2.5
②		2.5	8
③		10	2.5
④		10	8
⑤	bend	2.5	8

In the case ①, The cycle of STREEM is set to 1000. The initial velocity in X direction is set to2.5m/s, the initial velocity in Y、Z direction is set to 0 m/s . The velocity calculation result will appear negative situation because of system iterative calculation. The velocity profile diagram in each direction , X-direction velocity profile diagram, top view of particle distribution, Y-direction Particle distribution diagram, velocity vector diagram, velocity contours are shown in figure 5、figure 6、figure 7、figure 8、figure 9、figure 10。

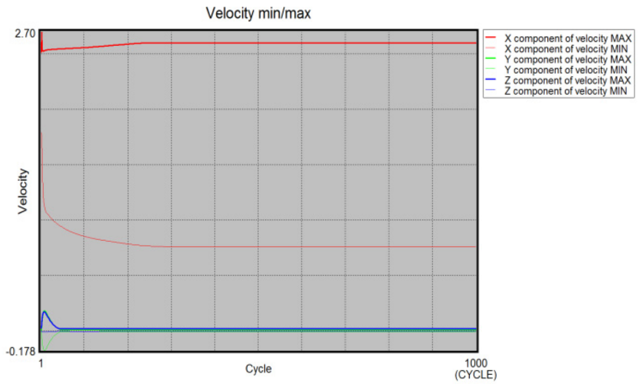

Fig. 5. The velocity profile diagram in each direction

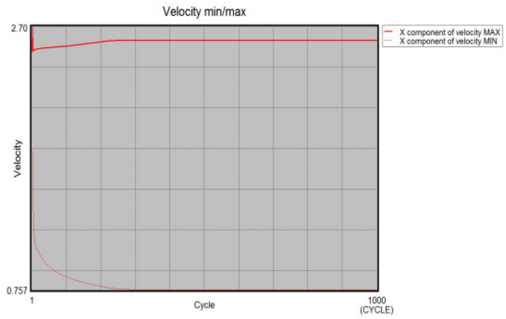

Fig. 6. X-direction velocity profile diagram

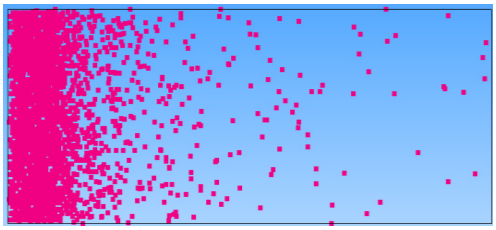

Fig. 7. Top view of particle distribution

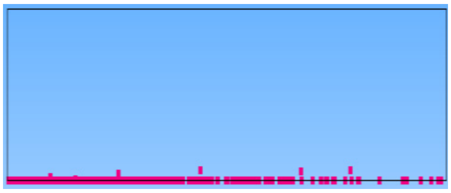

Fig. 8. Y-direction Particle distribution diagram

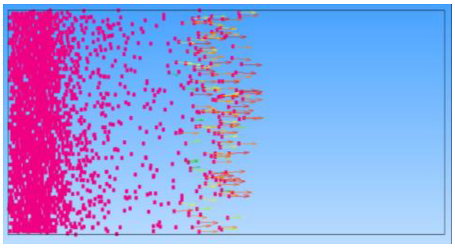

Fig. 9. Velocity vector diagram

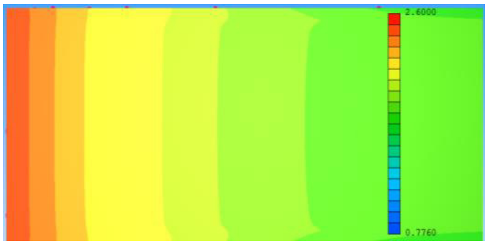

Fig. 10. Velocity contours

In the case ②, the initial velocity in X direction is set to 8m/s. Because the stable period of particles motion is around 250 known by condition 1, so the cycle of following condition is set to 500. The velocity profile diagram in each direction , X-direction velocity profile diagram， top view of particle distribution, Velocity contours are shown in figure 11、figure 12、figure 13、figure 14.

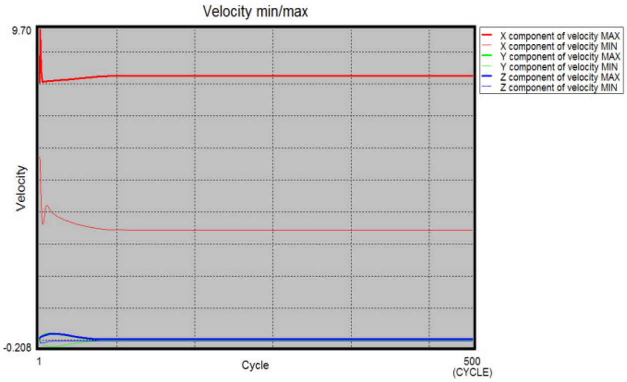

Fig. 11. The velocity profile diagram in each direction

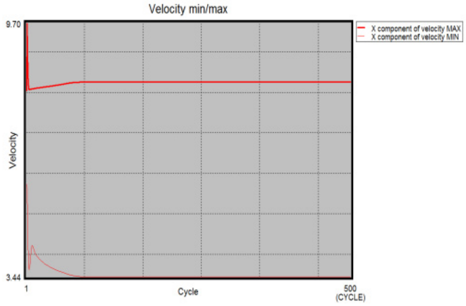

Fig. 12. X-direction velocity profile diagram

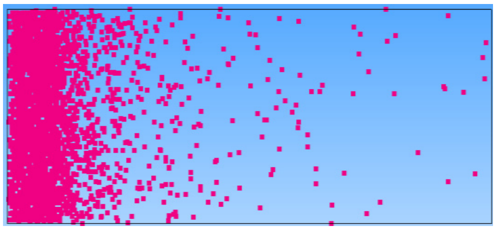

Fig. 13. Top view of particle distribution

Fig. 14. Velocity contours

In the case⑤, the initial velocity in X direction is set to 8m/s. The velocity profile diagram in each direction, X-direction velocity profile diagram, top view of particle distribution, velocity contours are shown in figure 15、figure 16、figure 17、figure18.

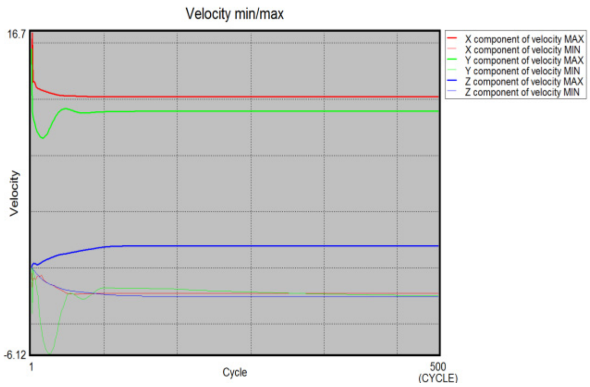

Fig. 15. The velocity profile diagram in each direction

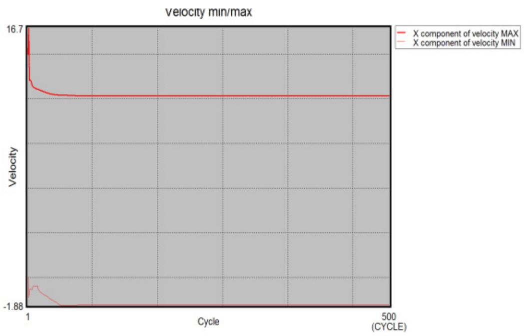

Fig. 16. X-direction velocity profile diagram

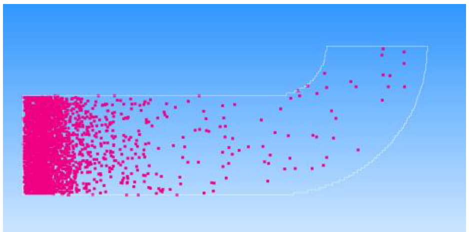

Fig. 17. Top view of particle distribution

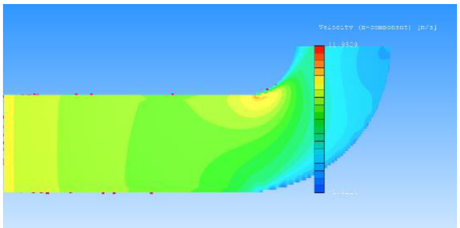

Fig. 18. Velocity contours

3. Results and analysis

The simulation results show that the particles motion presents three states: blown, adhered to the bottom of the duct, suspension. The detailed results are shown in Table 3. We can draw the following conclusions from Table 3. ① Most of the particles distribute in the viscous sublayer; ②The particles suspended and being blown account for a very small number;③The number of particles being blown and suspended increases slightly when we fix particle size and increase the wind initial velocity, but the difference is not large; ④The ratio of particles being blown in the straight pipe is more than bend at the same velocity and particle size, so there are certain obstacles for particle motion in bend.

Table 3. The detailed results

Case	Particles being blown	Adhered to the bottom of the tube	Suspended particles	Stable period
1	63	2931	6	255
2	71	2921	8	77
3	74	2923	3	250
4	77	2913	10	75
5	45	2944	11	130

In five cases, particles distribution in duct can achieve stable approximately 250 cycle (5 min). PM2.5 and PM10 stable period chart of motion at different wind velocity are shown as charts 1and 2. Particles of different size at same velocity stable periodic chart is shown as chart 3. Particles at same movement condition in different pipe sections stable periodic chart is shown as chart 4. Chart 1 and 2 show the larger the wind speed, the faster the particles with the same size reaching stable distribution. Chart 3 shows the motion stable time of particles in different sizes at same velocity is same basically. Chart 4 shows the particle motion reach stable easily in the straight pipe than bend at the same motion condition. From the X- direction velocity profile diagram and Velocity contours, we can know that the velocity change of particles increases sharply in the beginning, then decreases, remains stable finally. The larger the initial velocity, the greater velocity change at the entrance. The final velocity (X direction) of particles of different size is same basically in the same duct with the same initial velocity(X direction). PM2.5 and PM10 are generally deposited on the bottom of the pipe within the range of the allowable wind velocity in the air conditioning system.

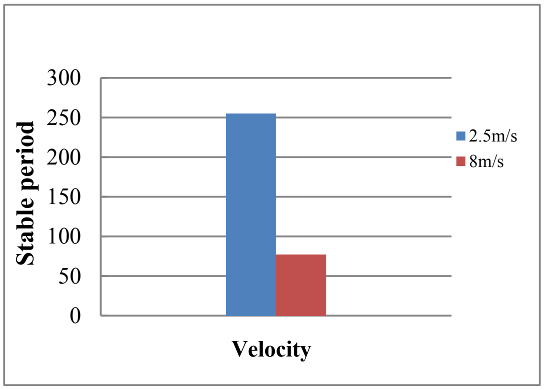

Chart 1. PM2.5 Stable periodic chart at different velocity

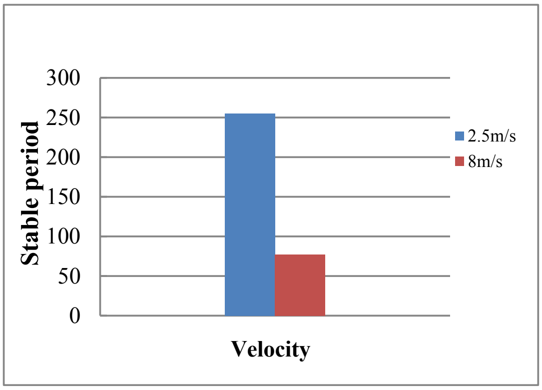

Chart 2. PM10 Stable periodic chart at different velocity

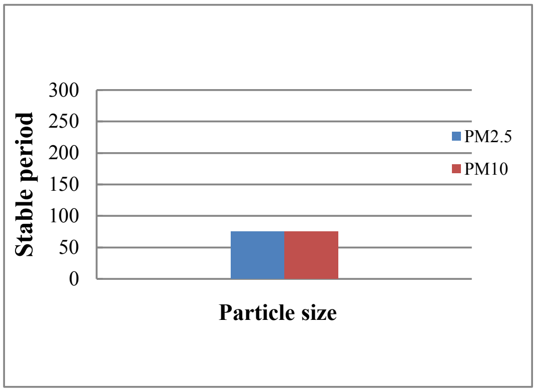

Chart 3. Particles of different size at same velocity stable periodic chart

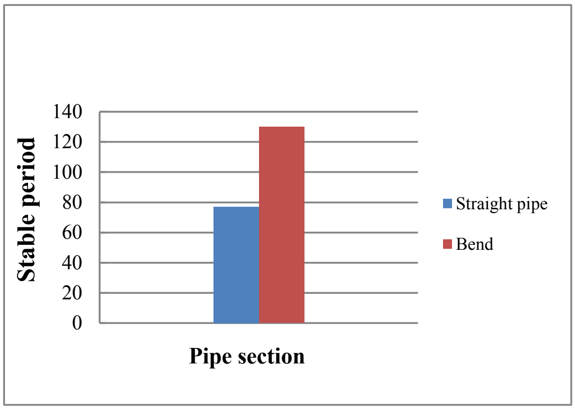

Chart 4. Particles at same movement condition in different sections tube stable periodic chart

4. Conclusions

More than 97% of PM2.5 and PM10 are deposited on the bottom of the pipe within the range of the allowable wind velocity in the air conditioning system. So we should clean the ventilation duct regularly. The velocity change of particles increase sharply in the beginning, then decrease, stabilized finally; the final velocity (X direction) of particles of different size is same basically in the same duct with the same initial velocity(X direction).

Acknowledgement

This research is supported by the Fundamental Research Funds for the Central Universities of China (DUT14QY24), the National Nature Science Foundation of China (51308088), the Twelfth Five-Year National Technology Key Project (2012BAJ02B05) and the national environmental protection special foundation " Indoor and outdoor atmospheric particles permeability coefficient and Pollution Control Strategies "(201509063-04).

References

[1] F. Wei, Rs. Chpamna, Research on Impact of Air Pollution on Respiratory Health, China Environmental Science Publishing House, Beijing, 2001.

[2] B. Zhao, J. Chen, Numerical Analysis of Particle Deposition in Ventilation Duct. Building and Environment in Press, Corrected Proof, Availale online 17, May, 2005.
[3] Y. Ren, Particle deposition in air conditioning and ventilating duct fittings, Master Thesis, Donghua University, 2006.
[4] L. Zhen, The air microbes transmit and disinfection control method, Ph.D. Thesis, Harbin Institute of Technology, 2007.
[5] Z. Xu, Principle of Air Cleaning Technology, Tongji University Press, 1998.